Construction and Performance of the NA62 RICH detector

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RICH 2016

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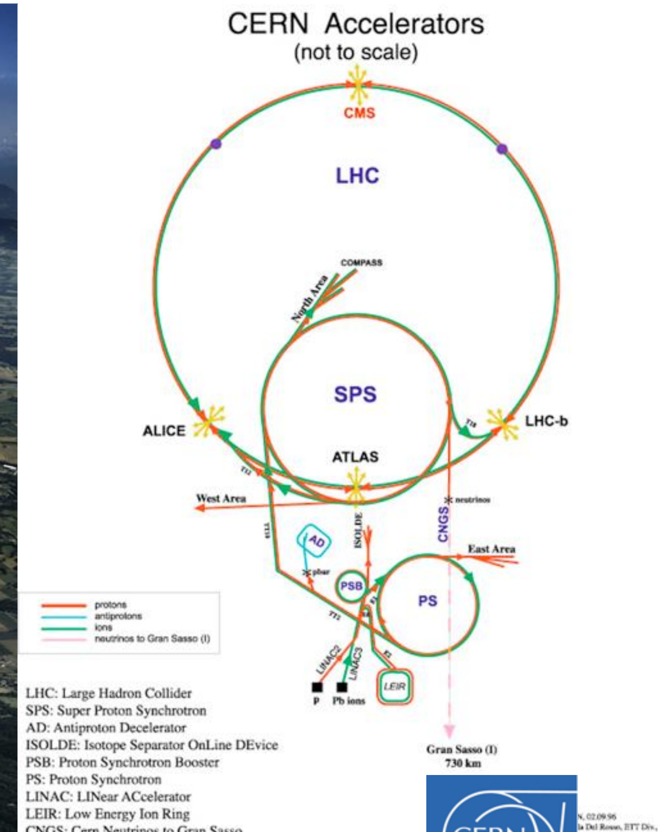
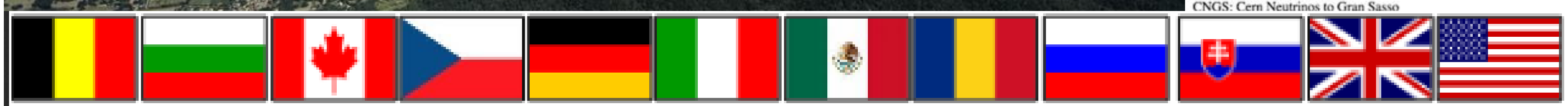
Outline

- ➔ The NA62 experiment at CERN
- ➔ The RICH design and construction
- ➔ The RICH performance during the 2015 run
- ➔ First results from the 2016 run
- ➔ Summary and Outlook

The NA62 experiment at CERN





Birmingham, Bratislava, Bristol, Bucharest, CERN, Dubna (JINR), Fairfax, Ferrara, Florence, Frascati, Glasgow, Liverpool, Louvain-la-Neuve, Mainz, Merced, Moscow(INR), Naples, Perugia, Pisa, Prague, Protvino (IHEP), Rome I, Rome II, San Luis Potosi, SLAC, Sofia, TRIUMF, Turin, Vancouver(UBC) → ~ 200 participants

The NA62 experiment

Measurement of the Branching Ratio of the decay $K^+ \rightarrow \pi^+ \nu \bar{\nu}$

- Theoretically very clean, sensitive to physics beyond Standard Model
- $BR_{TH}(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = (0.84 \pm 0.10) \times 10^{-10}$ SM@NLO

  [Buras et al., JHEP 11 (2015) 033; Brod et al., Phys.Rev. D83 (2011) 034030]
- $BR_{EX}(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = (1.73^{+1.15}_{-1.05}) \times 10^{-10}$ E787/949@BNL

  [BNL E787/E949: Phys.Rev. D77 (2008) 052003; Phys.Rev. D79 (2009) 092004]

Schedule

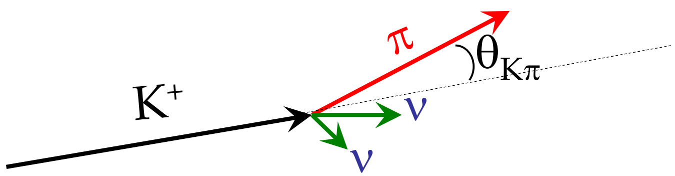
2012-2014:
Detector Installation & Techn. Run
Oct-Dec 2014:
NA62 Pilot Run
Jun-Nov 2015:
Physics Run @ Low intensity
2016-2018:
Physics Run

NA62 - Experimental principles

- Goal → 10% precision Branching Ratio measurement
- $O(100)$ $K^+ \rightarrow \pi^+\nu\bar{\nu}$ events in ~ three years of data taking

Very challenging experiment

Weak signal signature



$m^2_{miss} = (P_K - P_\pi)^2$

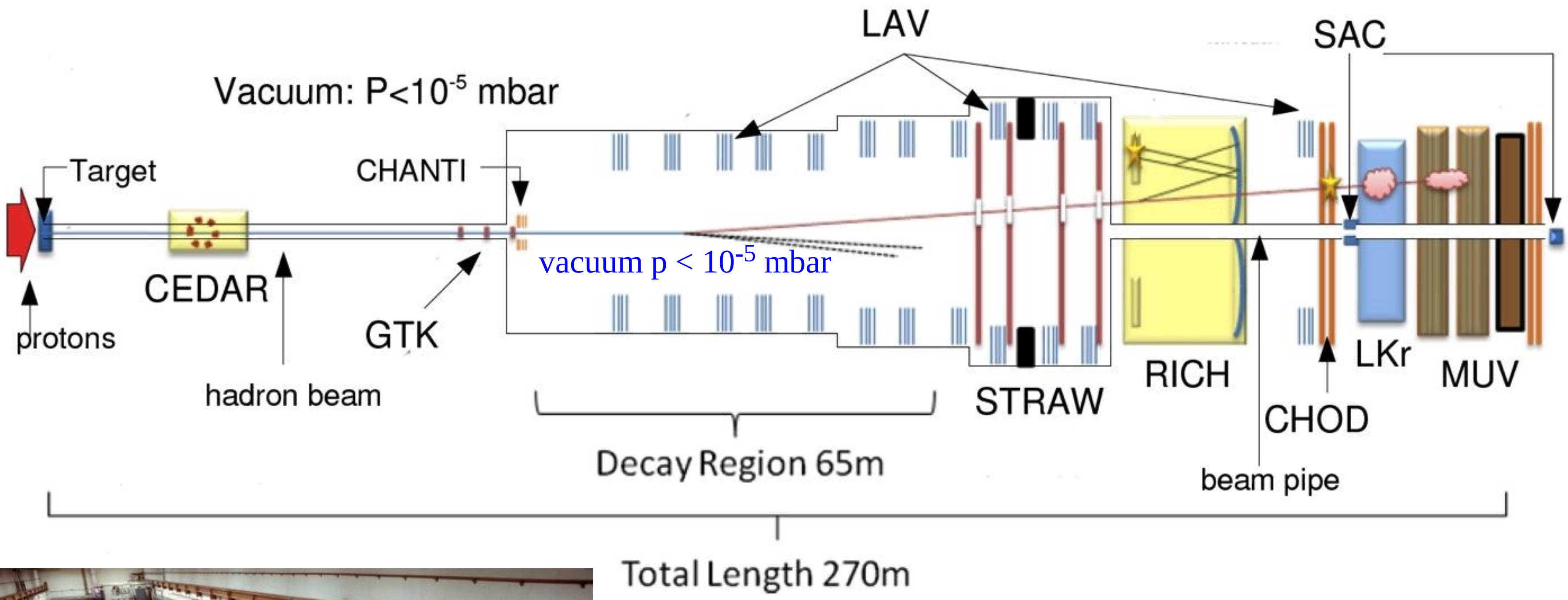
➔ Statistics
- BR(SM) ~ 8.4×10^{-11}
- Acceptance: 10%
- K decays: 10^{13}

- Main background:
  $K^+ \rightarrow \mu^+\nu$ ($K_{\mu 2}$) BR = 63.4%
- Rejection factor at least 10^{-12}
  - Kinematics : $10^{-4} \div 10^{-5}$
  - Veto for muons ~10^{-5}
  - Particle Identification:
    μ suppression < 10^{-2} → **RICH**

Huge background

Decay	BR
$\mu^+\nu$ ($K_{\mu 2}$)	63.5%
$\pi^+\pi^0$ ($K_{\pi 2}$)	20.7%
$\pi^+\pi^+\pi^-$	5.6%
$\pi^0 e^+\nu$ (K_{e3})	5.1%
$\pi^0\mu^+\nu$ ($K_{\mu 3}$)	3.3%

Experiment and beam



- 400 GeV/c SPS primary protons
- 3 x 10^{12} protons/pulse
- 75 GeV/c unseparated hadron beam ($\Delta p/p \sim 1\%$)
- Kaon component → 6%
- 750 MHz → 50 MHz kaons→ 5 MHz decays
- 4.5 x 10^{12} K^+ decays/y → SES ~ 10^{-12}

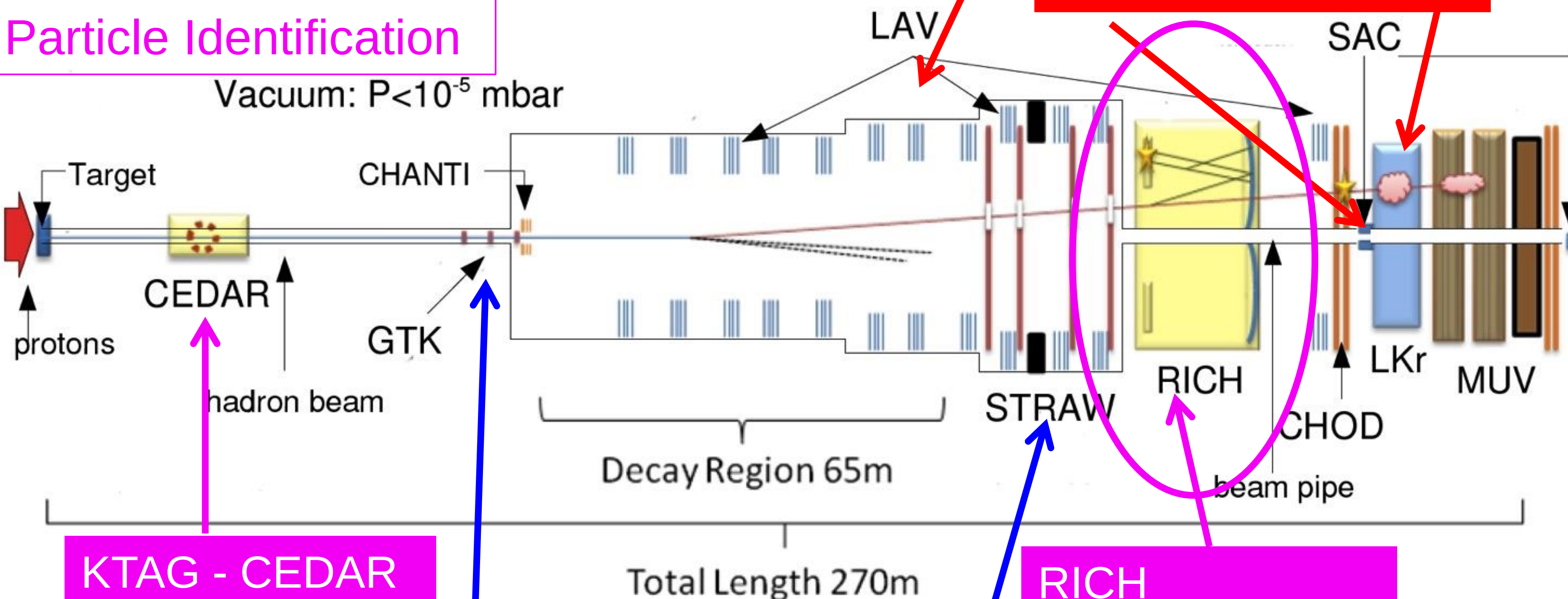
Detector layout

Beam and secondary particle tracking

Hermetic photon vetoes

Particle Identification

LAV	8.5 - 50 mrad
LKr	1- 8.5 mrad
SAV	< 1 mrad



KTAG - CEDAR
K^+ identification

GIGATRACKER
3 Si-pixel stations σ_t < 200

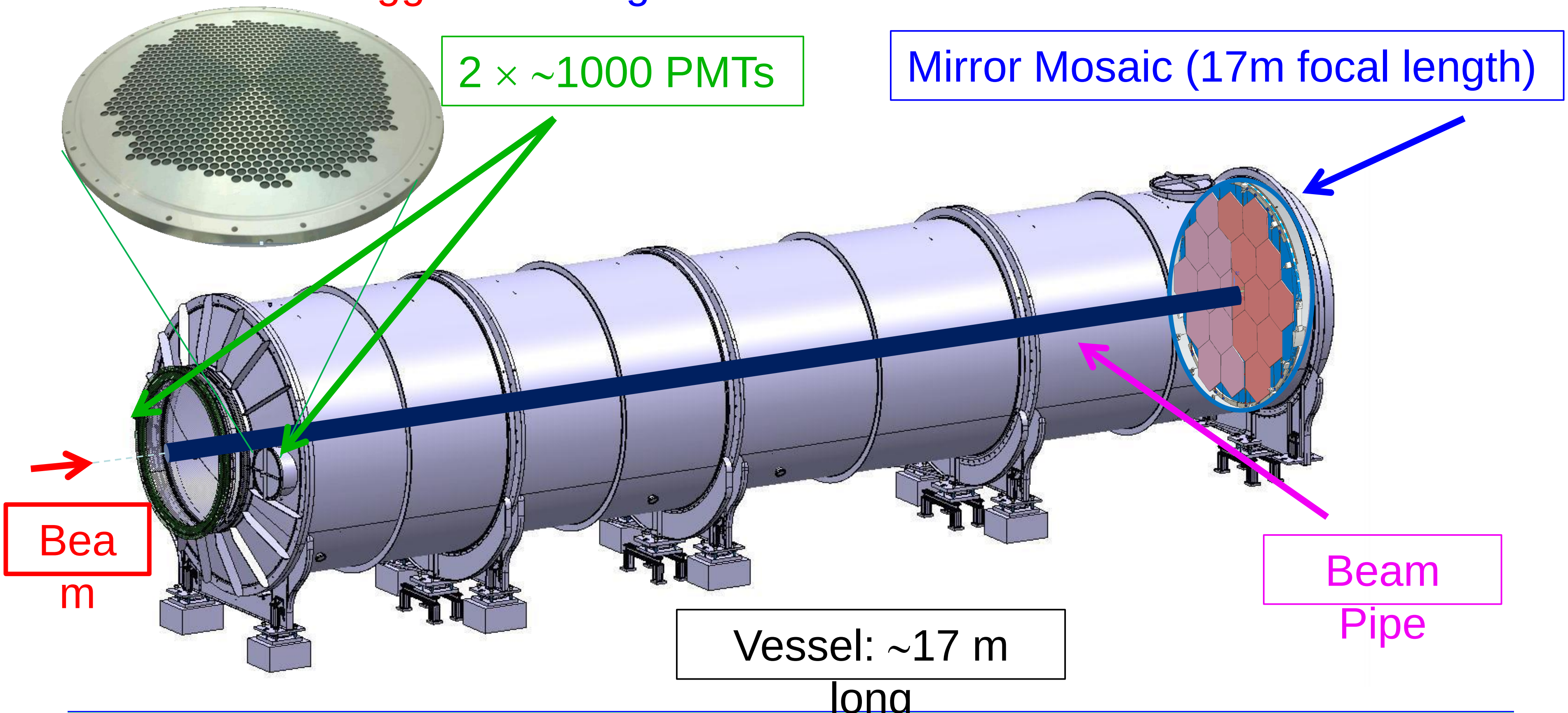
RICH
π/μ identification

STRAW chambers in vacuum
4 stations + dipole magnet

The NA62 RICH detector

REQUIREMENTS

- Muon contamination in the pion sample ≤ 1% in 15 < p < 35 GeV/c momentum range
- Measure pion crossing time with a resolution < 100 ps
- Provide a L0 trigger for charged tracks



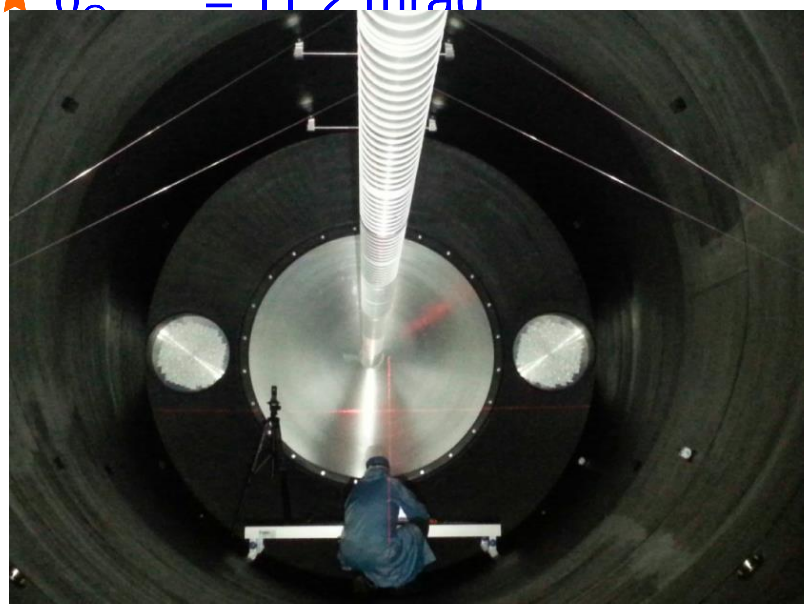
Vessel

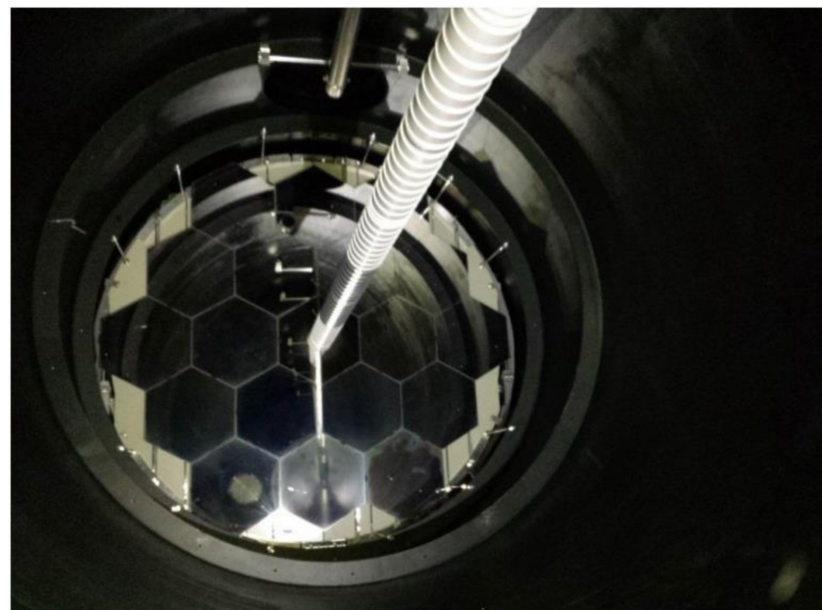
- Vacuum proof tank 17 m long in structural steel
- 4 cylindrical sections of decreasing diameter (4 $\rightarrow$ 3.4 m) and different lengths
- Beam pipe ($\varnothing$ 182 mm) going through
- Thin Aluminium entrance and exit windows, overall volume ~ 200 m^3

Radiator

Neon gas slighly above atmospheric pressure

- full efficiency requires $\rightarrow p_{threshold} = m / \sqrt{(n^2-1)} = 12.5$ GeV/c for π
- appropriate refractive index $(n-1) = 62.8 \times 10^{-6}$ at $\lambda = 300$ nm (small dispersion)
- good light transparency in visible and near-UV, low chromatic dispersion
- low atomic number to minimize radiation length
- θ_C = 11.2 mrad

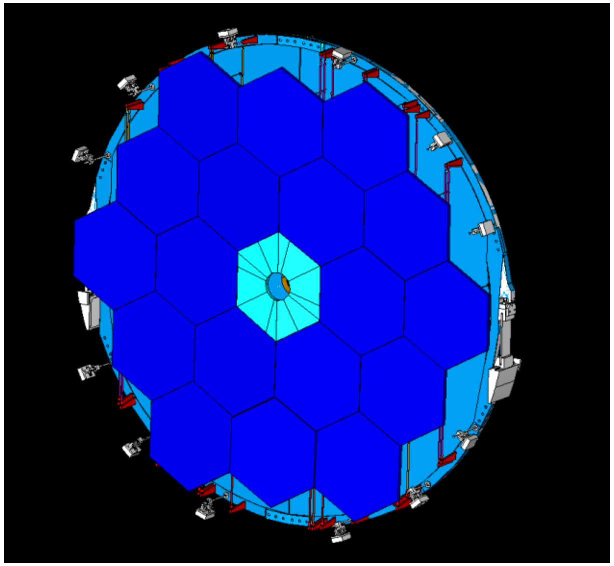


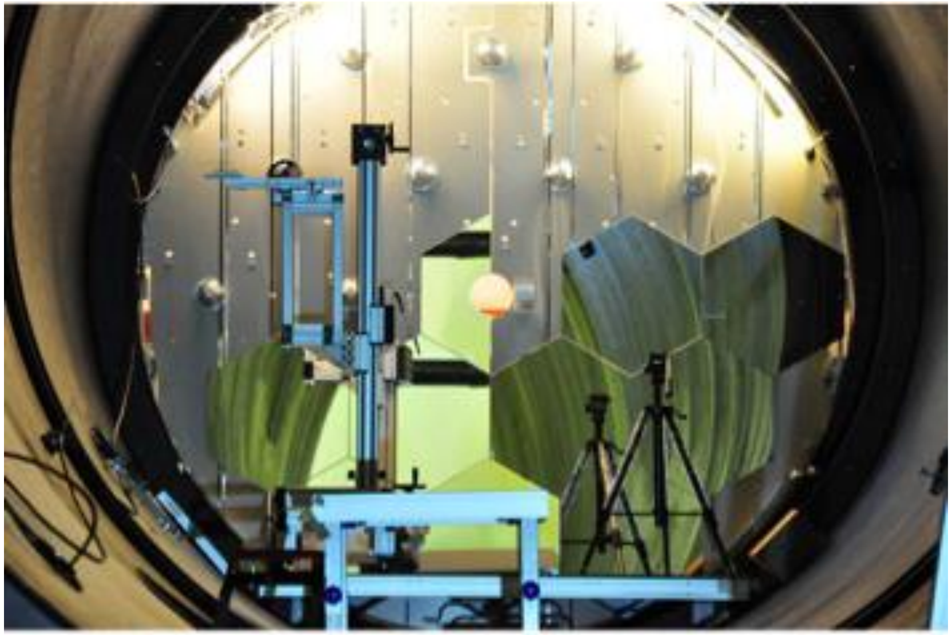


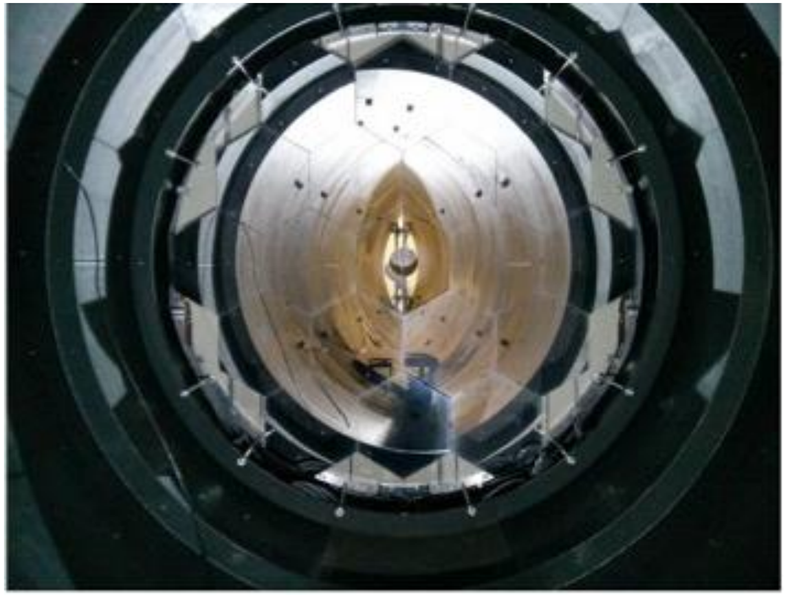
RICH performance rather immunes to impurities: no gas renewal

Mirror layout

- Mosaic of 20 spherical mirrors to reflect Cherenkov light
- 18 hexagonal mirrors (35 cm side)
- 2 semi-hexagonal with hole for beam pipe
- Spherical, nominal radius of curvature (34 ± 0.2 m)
- 2.5 cm thick glass, Al coat + thin dielectric film
- Average reflectivity ~ 90% in 195-650 nm
- $D_0 \leq 4$ mm







Mirror support and alignment system

- ✓ Al honeycomb structure, 5 cm thick, divided in two halves
- ✓ Mirrors supported by a dowel, in the back of the mirror
- ✓ Two aluminium ribbons keep the mirror in equilibrium and allow its orientation
- ✓ A third vertical ribbon is used to avoid mirror rotations
- ✓ Piezo motors, out of the acceptance, allow a remotely controlled orientation for alignment

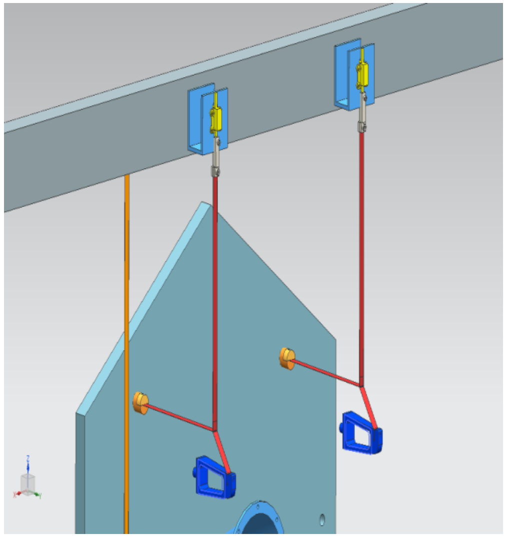


Photo-detection system

- Reflected light collected by 1952 PMTs, 18 mm pixel size
- PMTs assembled in a compact hexagonal packing on two aluminium disks placed at the upstream endcap
- UV glass window, 16 mm ∅ (8 mm active ∅) separate neon from air
- Winston cones to collect ligth
- Hamamatsu R7400U-03
  - Sensitivity range 185-650 nm (420 nm peak)
  - Gain 1.5×10^{6} at working point = 900 V
  - Q.E. ~ 20% at peak
  - 280 ps time jitter (FWHM)
- Custom made HV divider

Front-end and read-out system

RICH front-end

- Custom-made current amplifiers with differential output
- NINO chips used as discriminators
- 64 boards, 32 channels per board

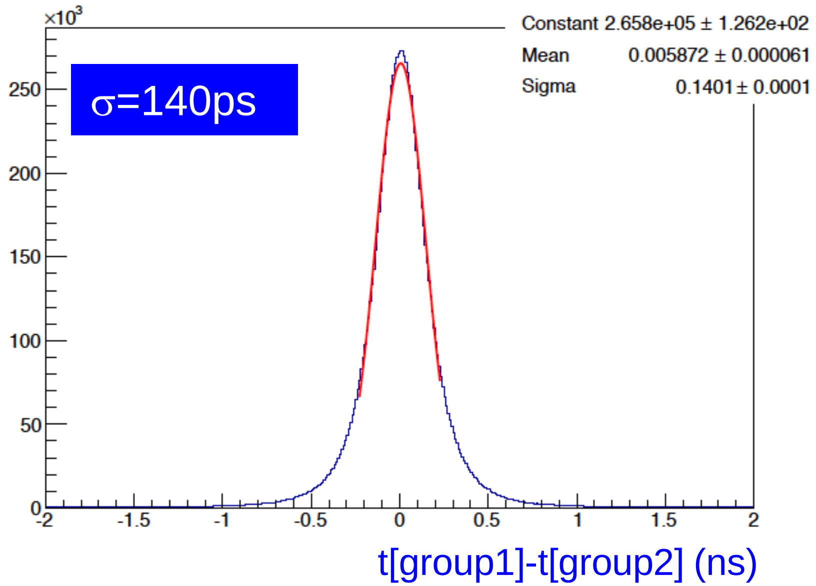
RICH read-out:

- 128 channels TDC daughter Boards (TDCB), each one housing 4 CERN HPTDC
- 5 FPGA based TEL62 mother boards (4 for the 2000 PMTs, 1 for the multiplicity read-out used to produce the L0 trigger), each one housing 4 TDCBs
- Trigger primitives are built in parallel with the readout on the same TEL62 board

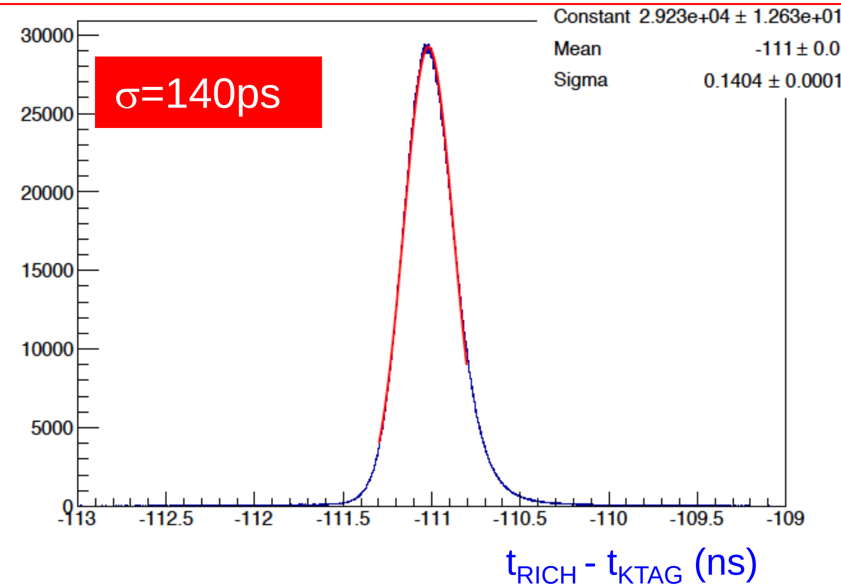
Time resolution

Results from 2014 pilot run

The intrinsic RICH time resolution



Time difference btw the average time of a Cherenkov ring and the KTAG time



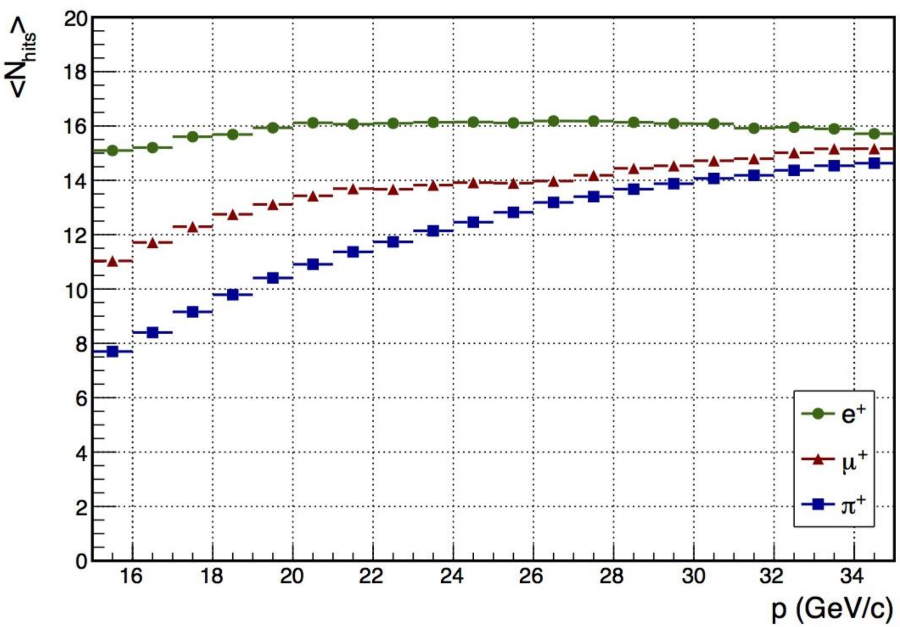
- Detected photons of one Cherenkov ring are divided in two groups
- Time difference of each group is plotted
- Time resolution of the full ring is ~ 0.5× σ

Measured event time resolution ~ 70 ps

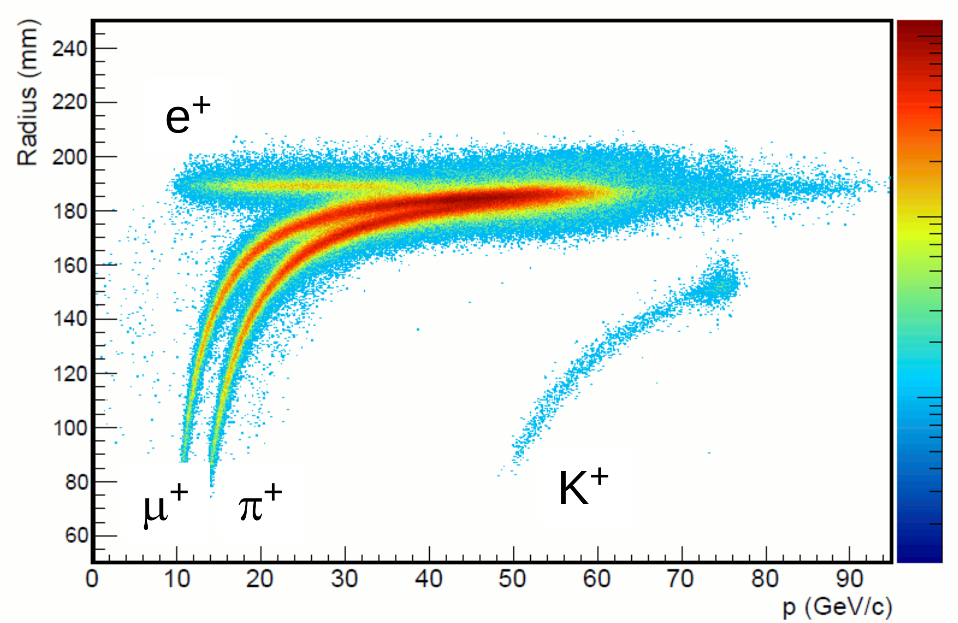
RICH Particle Identification

Preliminary results from 2015 run

- 2015 run July-November
- Intensity: (3 – 13) x 10^{11} ppp (10 – 40% of nominal)
- Samples of charged pions, muons and positrons selected using calorimetric and spectrometer information



Number of hits per Cherenkov ring as a function of particle momentum



The Cherenkov ring radius as a function of particle momentum

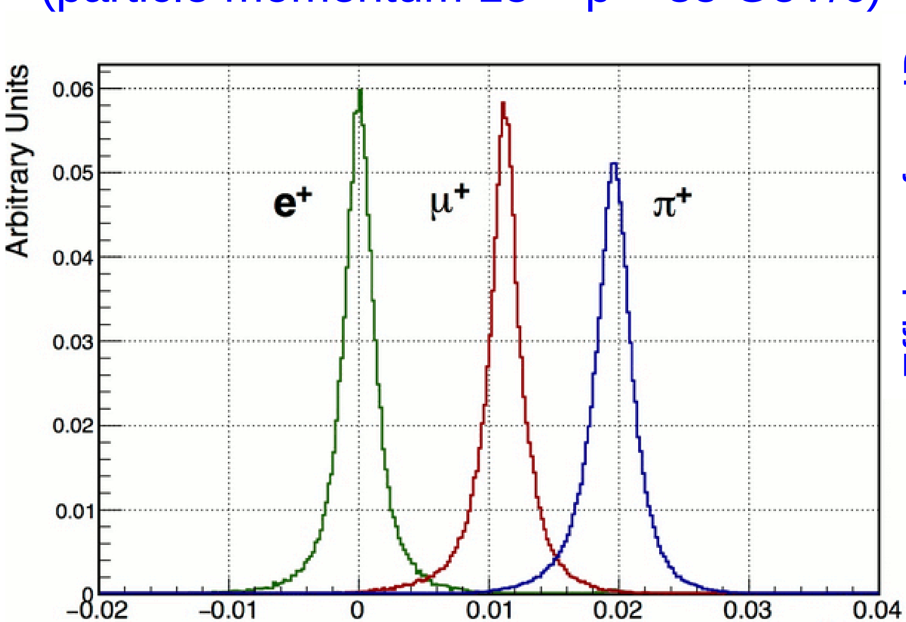
Pion-Muon separation

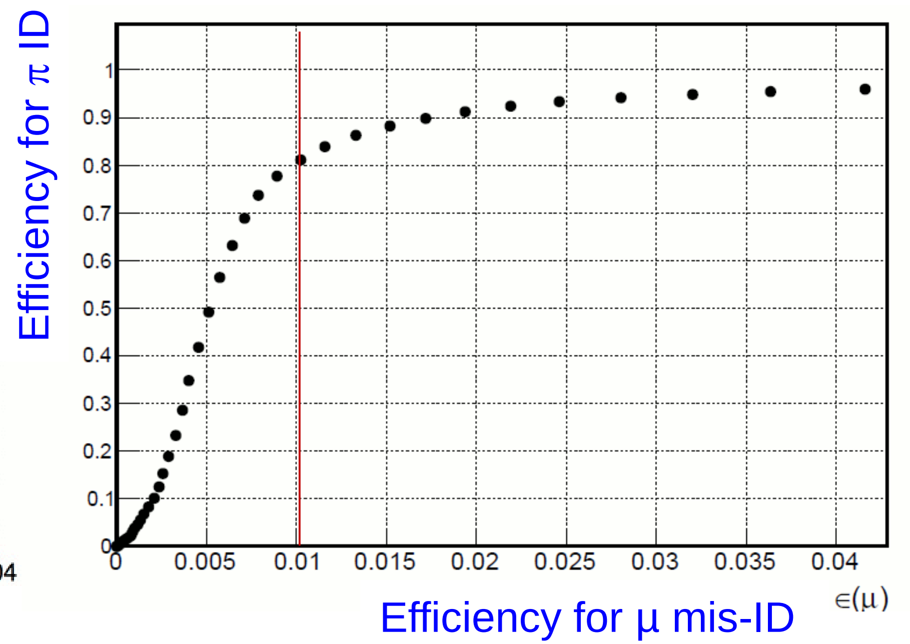
Preliminary results from 2015 run

Particle squared mass reconstructed using the velocity from the RICH and the momentum from the spectrometer

(particle momentum 15 < p < 35 GeV/c)

Pion identification efficiency as a function of muon mis-identification





For 80% π ID efficiency a 1% μ mis-ID efficiency is observed

RICH Maintenance

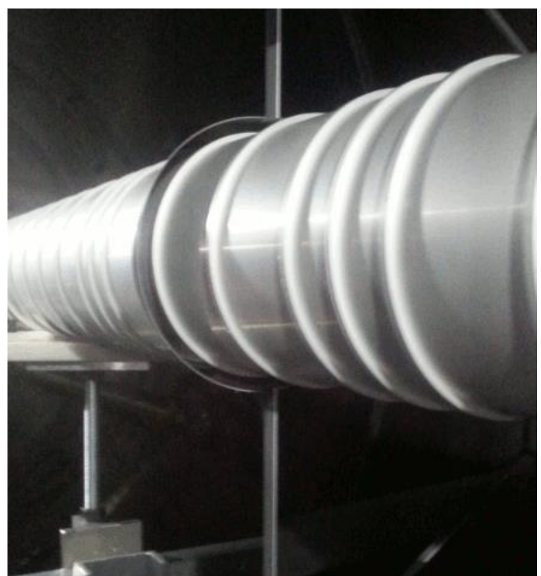
During the 2014 and 2015 runs the RICH mirrors alignment was not optimal

→ need of better performance in the pion-muon separation

→ maintenance carried out in the 2015-2016 winter shutdown

Main interventions:

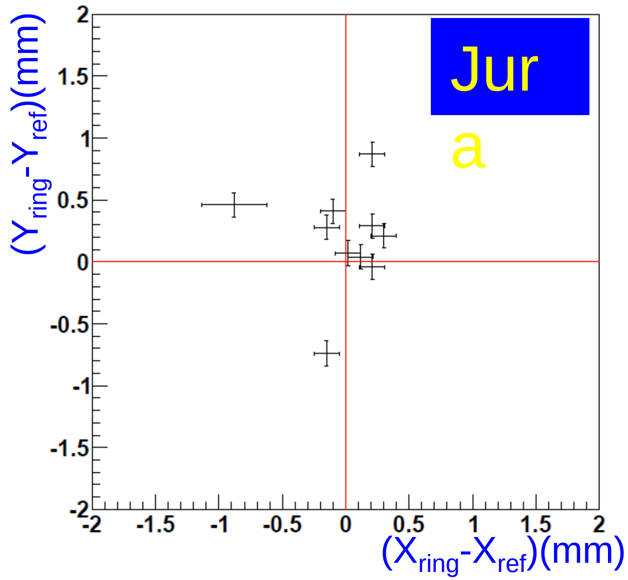
- ✓ Replace the two semi-hexagonal central mirrors, partially damaged during the installation of the beam pipe in 2014
- ✓ Replace some piezomotors

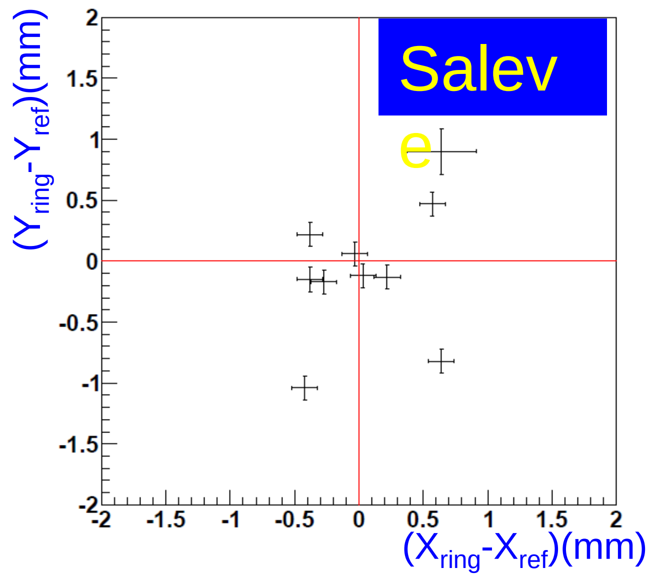


Mirrors alignment

Align mirrors remotely, 2016 data

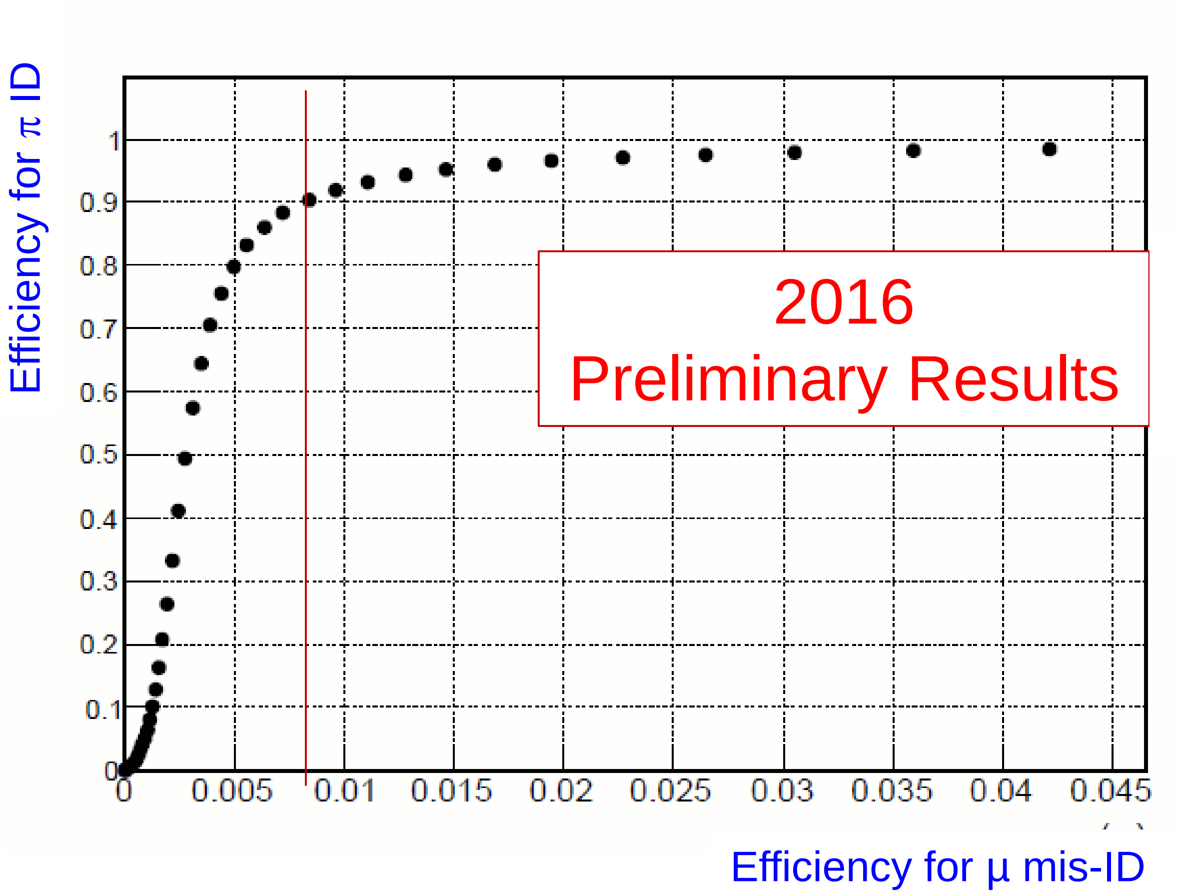
- ✓ Semi-hexagonal mirrors choosen as reference, separately for Jura and Saleve side
- ✓ Tracks reconstructed using the spectrometer and extrapolated to the PM plane
- ✓ Select rings fully contained in a single mirror
- ✓ Compare the position of the ring center on the PMT disk with the position predicted by the extrapolation
- ✓ Measured misalignment corrected using piezomotors, 2 - 3 iterations





All mirrors aligned within ± 1 mm with respect to the reference

2016 preliminary results



For 90% π ID efficiency a 0.8% µ mis-ID efficiency is observed

Summary and Outlook

- ✓ Construction, installation and commissioning of the RICH detector completed in time to meet the NA62 data taking schedule

- ✓ Pilot run in 2014 and run in 2015 at low intensity
  - ✓ Excellent time resolution from the first data
  - ✓ Good overall performance for physics analysis

- ✓ Physics run in 2016
- ✓ All mirrors aligned within 1 mm wrt reference
- ✓ The measured performance fulfill all the requirements

  - ❖ Time resolution ~ 70 ps
  - ❖ Muon mis-ID efficiency < 1% for 90% pion ID efficiency

- ✓ Data taking will continue in 2017 and 2018

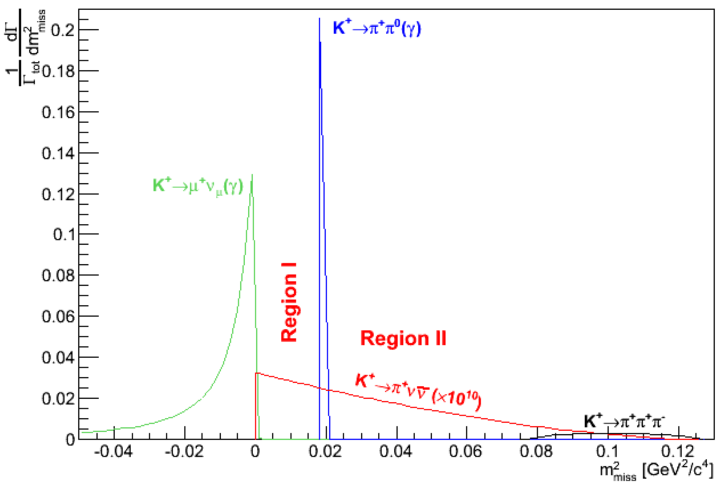

Thank you!

Additional information

Background and kinematics

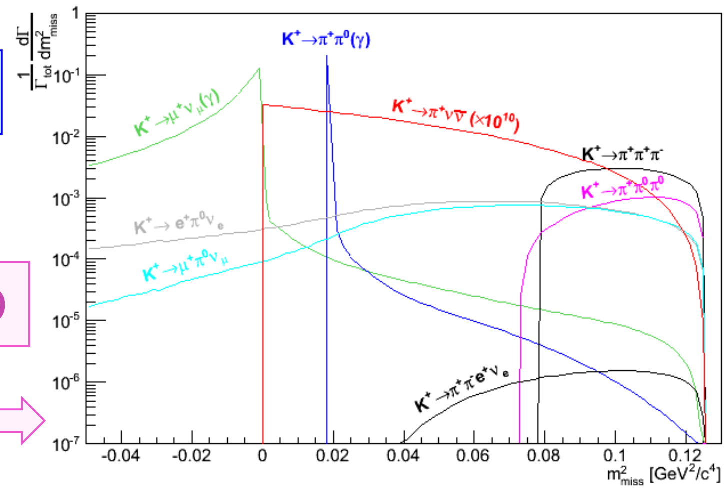
92% Bkg separated from signal by kinematic cuts

8% not separated



missing mass

Veto and PID



$m^2_{miss} = (P_K - P_\pi)^2$ defines low bkg signal regions separated by $K^+\to\pi^+\pi^0$

extend in the signal region, kinematics doesn't help

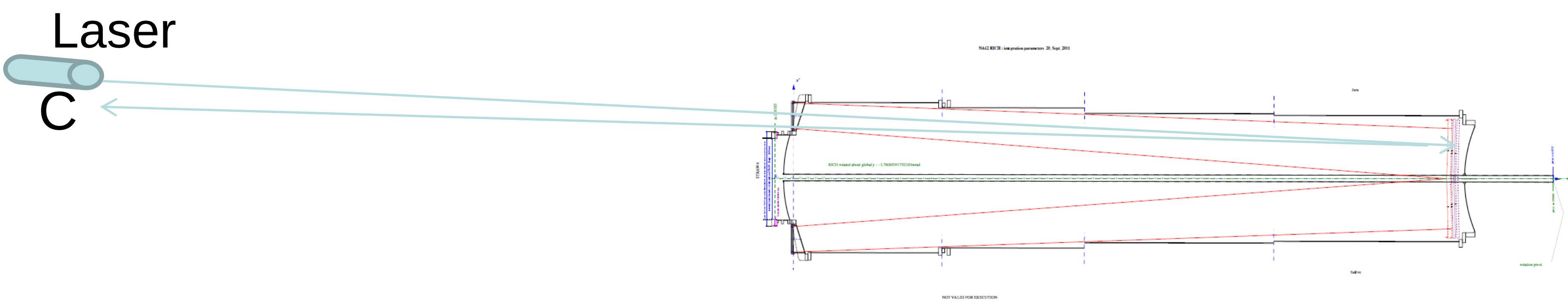
- ✓ high resolution m^2_{miss} reconstruction
- ✓ measure precisely kaon and pion momenta
- ✓ keep multiple scattering as low as possible

Gigatracker (kaon)
Straw chambers (pion)

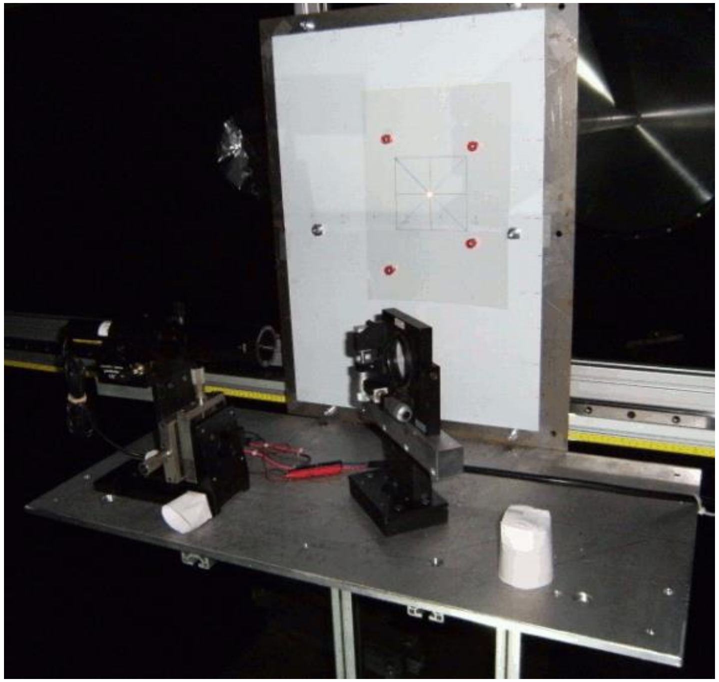
- ✓ Suppress $K^+\to\pi^+\pi^0$ background
- ✓ Reject offline decays with γ
- ✓ K^+ identification in the had beam
- ✓ 10^{-3} $\pi-\mu$ separation

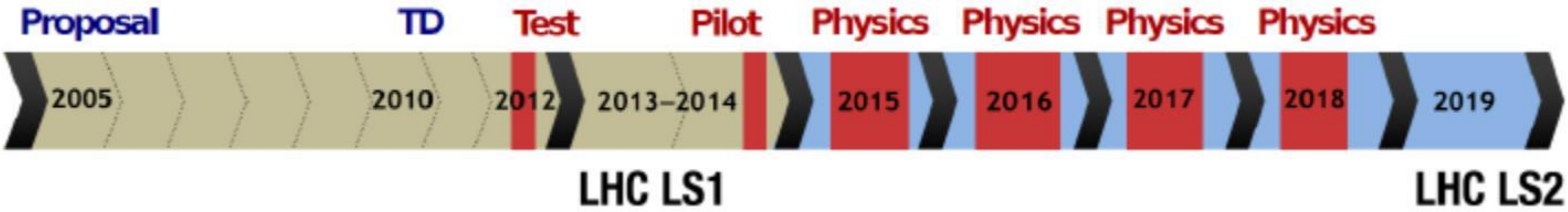
Photon veto system
Particle Identification

Mirrors pre-alignment



- Before beam pipe installation and vessel closing
- All mirrors pre-aligned using a laser
- The laser is placed in the Center of Curvature, C, of the mirror mosaic
- The reflected laser beam must come in the same position as the source
- Changing the laser beam angle with C as pivot, all the mirrors of one mosaic half can be illuminated and aligned
- If C is not accessible
- Put in C the optical image of the laser




Proposal
TD
Test
Pilot
Physics
Physics
Physics
Physics
2005
2010
2012
2013–2014
2015
2016
2017
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2019
LHC LS1
LHC LS2